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## Low Bus Voltage Hydrazine Arcjet System for Geostationary Satellites

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### Abstract

*The capabilities of arcjet propulsion systems were recently extended to accommodate operation on the NASDA Data Relay Test Satellite (DRTS) providing a power bus voltage between 31 and 51.5 VDC. This paper summarizes the newly attained qualification status of the MR 512 arcjet system demonstrating the flexibility of the current design. A redesign of the Power Processing Unit (PPU) became necessary as well as a delta-qualification of the thruster to validate spacecraft integration, and to provide compliance with the DRTS satellite environmental requirements. Two types of thrusters with different thrust levels were made available to meet mission requirements. The delta-qualification included a pyro-shock test, vibration tests to a higher level than previously tested, and performance mapping beyond the original range. Included in the paper is an assessment of the PPU performance characteristics as well as the discussion of the system operation and system telemetry.*

### **Introduction**

The second generation MR 509 1.8 kW hydrazine arcjet system has been based on the MR 508 system, the first flight qualified 1.8 kW arcjet system, by incorporating lessons learned from the first flight missions. The design upgrade successfully extended the lifetime to a more demanding 13 years on orbit life. Its qualification history and flight experience have been described by Smith et al.<sup>[1]</sup> Consequently, the MR 510 2.2 kW hydrazine arcjet has been developed from the MR 509 system. The increase in power and incorporation of new technology enabled the arcjet to operate at higher performance. For more details on the MR 510 development and qualification history see <sup>[2]</sup> by Smith et al.

The new 1.8 kW MR 512 system was developed to provide greater versatility and increased environmental capabilities with an input voltage range of 31 to 51.5 VDC for use

on the Japanese NASDA Data Relay Test Satellite (DRTS). This paper describes the new system, and the power processing unit (PPU) as well as thruster related changes that became necessary for this application and proved the maturity and flexibility of arcjet systems.

Since the thruster design had already demonstrated adequate lifetime and performance for the DRTS mission, a new complete qualification of the thruster components was not necessary. A limited delta-qualification effort was required to show compliance with the environmental conditions during integration, launch, and on-orbit. Since the thruster integration on the satellite required thrusters with two different thrust levels (see chapter "Thruster Performance"), the two thrusters are now designated MR 512-A and -B respectively. A complete arcjet propulsion system for one satellite consists of four PPUs,

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	Non Operating	Pre-Firing, typically 30 minutes long	firing (2 thrusters at a time)
PPU			
- auxiliary power	4 in stby. mode	2 in stby. mode, 2 aux. enabled	2 in stby.
0.5 W stby.	2.0 W	1.0 W	1.0 W
10 W aux. enabled	0	20.0 W	0
- main power			2 enabled
	0	0	3544 W
Arcjets			
valves	0	0	1.5 W (2 open)
valve heaters	4 active, 50% duty cycle	4 active, 50% duty cycle	2 active on the non firing thrusters, 50% duty cycle
	22.0 W	22.0 W	11.0 W
gas generator heaters		active on the 2 thrusters to be fired	
	0	8.4 W	0
total	24.0 W	51.4 W	3557.5 W

Table 2: Average MR 512 System Power Consumption

The thruster had earlier been qualified for more than 1050 hours of operation with more than 1170 individual starts, most of these cycles consisted of a 1 hour on period followed by a 30 minute cool down phase. Thus, normally recommended burns can last up to 60 minutes. The thruster reaches steady state thrust and specific impulse levels within 2 minutes. The longer the burn period, the higher the average impulse and the overall fuel efficiency. At the end of the arcjet maneuver, the PPU receives a "STOP" command and the arc is extinguished. The valve is then closed.

During thruster off-times, only the valve heaters have to be activated thermostatically to prevent propellant freezing in the fuel lines near the valve, where the lines are exposed to open space and its low temperatures. The remainder of the propellant lines are routed inside the spacecraft at sufficient temperatures, or are equipped with line heaters to prevent freezing.

Both analytical and experimental plume studies of this thruster type show that plume - spacecraft interaction is benign and does not pose a problem for the typical arcjet installation on a spacecraft. Information from all arcjet equipped satellites on orbit confirm that no arcjet induced system degradation is detectable.

To determine the system status, the following telemetry signals are available from the arcjet system:

- PPU input voltage
- PPU output voltage
- PPU output current
- 2 PPU temperatures
- PPU error flag
- gas generator temperature
- valve temperature

These are either transmitted to the ground control station or are used by the on-board control computer to monitor the arcjet system

In the MR 509/510/512 arcjet family, the mass flow is controlled through the use of a fluid resistor which reduces the feed pressure in the gas generator and at the same time limits the mass flow to the desired range.

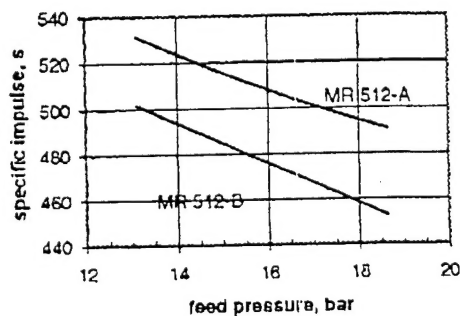
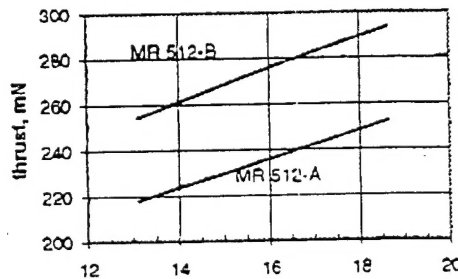
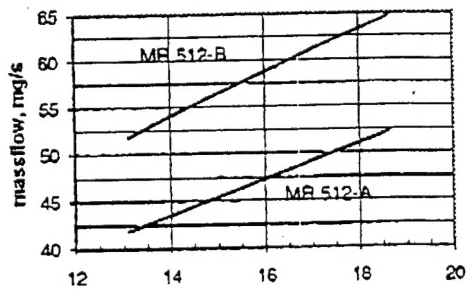


Fig. 2: Performance of the MR 512-A and -B Thrusters (25°C Propellant Temperature)

To accommodate the higher thrust level, a fluid resistor with a lower resistance, thus allowing a larger mass flow, was selected. The

required mass flow was first estimated based on the existing performance model, and the "equivalent feed pressure" for the MR 512-A thruster was calculated. During the MR 512 qualification tests, the -A thruster was performance mapped at feed pressures up to 31.1 bar, which is representative for the 20.7 bar feed pressure of the -B thruster. These tests established a preliminary performance model for the -B configuration as well as selection of the appropriate fluid resistor size for these thrusters.

Parallel to the thruster test at the new thrust level, the PPU was tested with a thruster at the higher mass flow levels to demonstrate the PPU capability to reliably start and operate the thruster under these conditions. A comparison of the thruster performance for the -A and -B thruster is given in Table 3 and Fig. 2.

Parameter	MR 512-A	MR 512-B
Nominal Feed Pressure (bar)	14.2 - 17.6	14.2 - 17.6
Mass Flow (mg/s)	44 - 50	54 - 62
Thrust (mN)	225 - 246	262 - 286
Specific Impulse (sec)	522 - 497	492 - 462

Table 3: Performance Comparison of MR 512-A and -B Thrusters at 25°C Fuel Temperature

#### Thruster Qualification

As already stated, the previously achieved qualification status of the arcjet thruster<sup>(1)</sup> was, with minor exceptions, adequate for the DRTS mission. The system requirements for total propellant throughput and the anticipated number of cycles will be met by the qualified 1170 starts and the total impulse capability of 866,500 Ns per thruster. This is equivalent to

thruster were found not to exceed 6.5 W conductive heating and 78 W radiative heating. The temperature of the arcjet mounting structure at the interface with the satellite varies with the specific design and is below 190 °C for the DRTS application.

The detailed thermal model was also used to assess soak back temperatures after firing on the valve and the spacecraft structure. No temperature limits were exceeded.

To allow a fast assessment of varying installation environments, a simplified thermal model was created that allows heat-load and temperature predictions in the critical areas during both firing and non firing conditions. It breaks the thruster down into a 19 node network with the thermal conductance between the nodes adjusted to meet the temperature predictions of the detailed model for steady state conditions.

### PPU Design

The PPU design baseline was the MR 509 PPU. It was, however, updated, and modified for a power bus voltage range of 31 to 51.5 VDC. PPU output characteristics remained unchanged. The MR 512 arcjet thruster requires high voltage arc starting pulses, controlled power start-up characteristics, and constant power. The thruster voltage can range from -105 V to -140 V while the power is maintained constant at  $1630 \pm 30$  W. Arcjet operation outside this envelope, especially at lower voltages, is possible, however with losses in efficiency and control stability.

The PPU power train (Fig. 3) consists of an EMI filter, and a DC to DC Switch Mode Converter power control. In addition there is an auxiliary housekeeping supply, a command interface, and telemetry signal generation, the two latter tailored to the DRTS requirements.

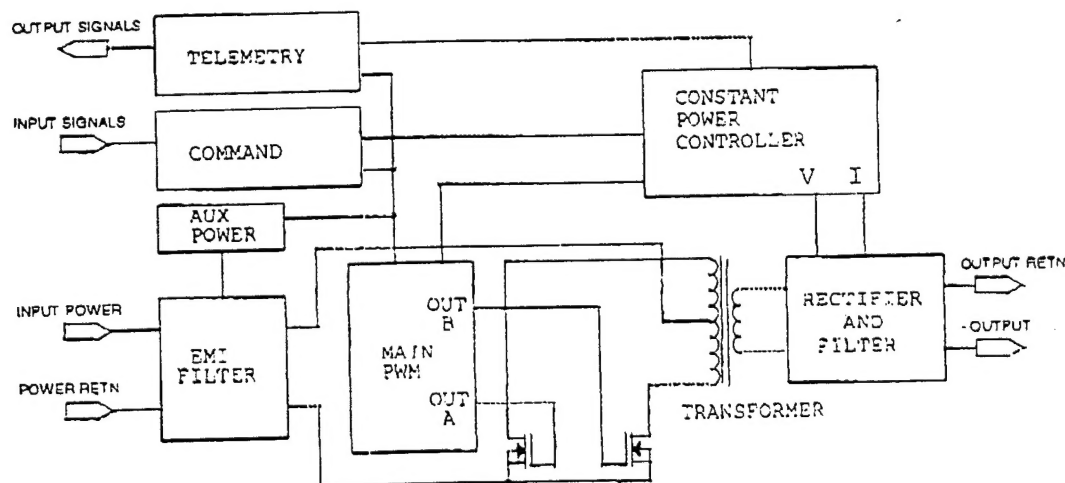


Fig. 3: MR 512 PPU Block Diagram

command interfaces and telemetry signals complied with customer requirements and functioned flawlessly at the system level. PPU testing with the AJT demonstrated system compatibility under all operating conditions.

Reliability levels are extremely high, achieved by selection of NASA approved components. Component operating stresses are within conservative (MIL-STD-975) derating guidelines. Radiation hardness is assured by selecting radiation hard components.

Thermal imaging of internal electronic components during the testing of the engineering unit demonstrated uniform heat distribution. All temperatures are well below component temperature ratings, thus increasing reliability.

The unit weight is approximately 6.2 kg, an increase over the MR 509 design. This can be explained by the weight of added copper to meet the efficiency goal for all input voltages. Mechanical design integrity was validated by vibration testing and finite element predictions for shock loads.

#### PPU Qualification

The general concept of the MR 512 PPU had been tested with an EDM-unit, which led to the qualification model. This unit, which is representative for the flight models, was subjected to a comprehensive qualification test, which it passed successfully. The qualification test included (among others):

- corona tests,
- EMI tests,
- sinusoidal and random vibration tests,
- thermal vacuum cycling,
- a high temperature burn in,
- firing into an arcjet thruster,
- and a
- 240 hour burn in.

These tests were separated by electrical functional tests, which verified the unit had successfully passed the previous test sequence.

The EMI test was performed to the MIL-STD-461 guidelines for:

- conducted emissions, methods CE01, CE03;
- radiated emissions, methods RE01, RE02;
- conducted susceptibility, methods CS01, CS02;
- radiated susceptibility, methods RS02, RS03;
- and
- spike susceptibility, method CS06.

Sufficient margin in all these areas was demonstrated.

The firing test verified the MR 512 PPU capability to reliably operate both the -A as well as the -B thruster. Included was a demonstration to successfully cope with gas ingestion and the resulting temporary brief arc instability.

#### Summary

Through the development of the new MR 512 arcjet system, the range of satellite buses for which arcjet thrusters are now qualified, could be greatly extended. This required design and qualification of a power processing unit for an input voltage of 31 to 51.5 VDC and additional environmental tests to the thruster design.

The MR 512 system showed the great flexibility of the arcjet design to accommodate different thrust levels, and increased environmental requirements. The change in thrust level could be met by changing the flow controlling fluid resistor. While the higher thrust unit has a lower specific impulse, it is sufficiently high to make hydrazine arcjets